

LA-UR-16-20597 (Accepted Manuscript)

Progress in the development of the MARBLE platform for studying thermonuclear burn in the presence of heterogeneous mix on OMEGA and the National Ignition Facility

Murphy, Thomas Joseph; Douglas, Melissa Rae; Fincke, James R.; Olson, Richard Edward; Cobble, James Allen; Haines, Brian Michael; Hamilton, Christopher Eric; Lee, Matthew Nicholson; Oertel, John A.; Parra-Vasquez, Nicholas Gerardo; Randolph, Randall Blaine; Schmidt, Derek William; Shah, Rahul C.; Smidt, Joseph Michael; Tregillis, Ian Lee

Provided by the author(s) and the Los Alamos National Laboratory (2016-09-01).

To be published in: Journal of Physics: Conference Series

DOI to publisher's version: 10.1088/1742-6596/717/1/012072

Permalink to record: <http://permalink.lanl.gov/object/view?what=info:lanl-repo/lareport/LA-UR-16-20597>

Disclaimer:

Approved for public release. Los Alamos National Laboratory, an affirmative action/equal opportunity employer, is operated by the Los Alamos National Security, LLC for the National Nuclear Security Administration of the U.S. Department of Energy under contract DE-AC52-06NA25396. Los Alamos National Laboratory strongly supports academic freedom and a researcher's right to publish; as an institution, however, the Laboratory does not endorse the viewpoint of a publication or guarantee its technical correctness.

Progress in the development of the MARBLE platform for studying thermonuclear burn in the presence of heterogeneous mix on OMEGA and the National Ignition Facility

T J Murphy, M R Douglas, J R Fincke, R E Olson, J A Cobble, B M Haines, C E Hamilton, M N Lee, J A Oertel, N A G Parra-Vasquez, R B Randolph, D W Schmidt, R C Shah, J M Smidt and I L Tregillis

Los Alamos National Laboratory, P. O. Box 1663, Los Alamos, New Mexico 87545 USA

E-mail: tjmurphy@lanl.gov

Abstract. Mix of ablator material into fuel of an ICF capsule adds non-burning material, diluting the fuel and reducing burn. The amount of the reduction is dependent in part on the morphology of the mix. A probability distribution function (PDF) burn model has been developed [6] that utilizes the average concentration of mixed materials as well as the variance in this quantity across cells provided by the BHR turbulent transport model [3] and its revisions [4] to describe the mix in terms of a PDF of concentrations of fuel and ablator material, and provides the burn rate in mixed material. Work is underway to develop the MARBLE ICF platform for use on the National Ignition Facility in experiments to quantify the influence of heterogeneous mix on fusion burn. This platform consists of a plastic (CH) capsule filled with a deuterated plastic foam (CD) with a density of a few tens of milligrams per cubic centimeter, with tritium gas filling the voids in the foam. This capsule will be driven using x-ray drive on NIF, and the resulting shocks will induce turbulent mix that will result in the mixing of deuterium from the foam with the tritium gas. In order to affect the morphology of the mix, engineered foams with voids of diameter up to 100 microns will be utilized. The degree of mix will be determined from the ratio of DT to DD neutron yield. As the mix increases, the yield from reactions between the deuterium of the CD foam with tritium from the gas will increase. The ratio of DT to DD neutrons will be compared to a variation of the PDF burn model that quantifies reactions from initially separated reactants.

1. Introduction

The success of inertial confinement fusion relies on the ability to implode a capsule of DT fuel in a way that prevents the introduction of capsule material into the fuel [1]. Mix of capsule material can reduce the performance of ICF capsules in a number of ways. Among these is the dilution of fusion fuel, resulting in lower number density of the reacting ions, and an overall reduction in nuclear yield.

The degree to which mix affects the yield is affected by the degree to which the mix is complete (Figure 1). For complete atomic mixing, the dilution is maximized. For incomplete

mixing, regions of locally higher fuel density can occur and the performance degradation is reduced.

The effect of incomplete, heterogeneous mixing on thermonuclear yield can be described using a probability distribution function (PDF) [2] to model the concentration of DT fuel within a region of mixed fuel and capsule material. The PDF model uses parameters provided by turbulent mixing models that attempt to capture the important physics in a computationally efficient manner, allowing large-scale simulations of imploding capsules. One such model is the BHR model [3] and its revisions [4, 5]. Results from the BHR model are used in conjunction with the PDF burn model to describe concentration variations at the sub-grid level to determine the effect on burn [6].

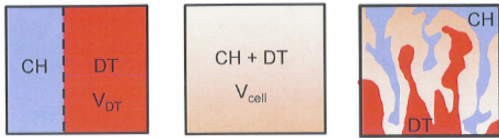


Figure 1. Computational cells in which the CH ablator and DT fuel are (left) completely separated, (center) completely atomically mixed, and (right) heterogeneously mixed with a range of concentrations.

2. Concept of the MARBLE experiment

Marble is an experimental campaign intended to quantify the effect of heterogeneous mix on fusion burn. Capsules filled with deuterated plastic foam and tritium gas will be imploded and the yield of 14-MeV DT neutrons will be measured to provide a measure of the degree to which the foam and gas mixed. In contrast to the case in which more complete mix of capsule material into fuel reduces the reactivity, increased mix of the components in this separated-reactant experiment increases the production of DT neutrons. To make the experiment less sensitive to shot-to-shot drive and capsule variations, the DT neutron yield will be normalized to the 2.45-MeV DD neutron yield to give the DT to DD yield ratio.

To vary the heterogeneity of the mix, the foam will be engineered to produce large “macropores” (Figure 2). The density of the interstitial foam will be set so that the average foam density in the capsule is known, and the gas pressure set so that the average concentration of deuterated plastic and tritium is known, and only the morphology of the mix changes. This morphology will be controlled by specifying the diameter of the macropores. Turbulent instability growth [7] with smaller characteristic length scales leads to faster development of atomic mix, so the smaller the macropore diameter, the more quickly and completely the components will mix to produce DT yield.

This design has a number of advantages over previous experiments:

- The amount and initial configuration of mix is defined (mix mass evolution removed)
- DT burn occurs near the center of the capsule where temperature gradients are less steep than at the ablator-fuel interface
- As in other separated reactant experiments [8], the DT yield is co-located with the mix

Simulations indicate that initial macropores with diameters of about 100 μm will result in significant heterogeneity at burn time, while macropores with diameters of about 10 μm will result in near fully atomically mixed components.

3. Status of the development of MARBLE

The ability to carry out the MARBLE campaign depends on developing the capability to fabricate the necessary targets. This includes the ability to create low-density deuterated foams,

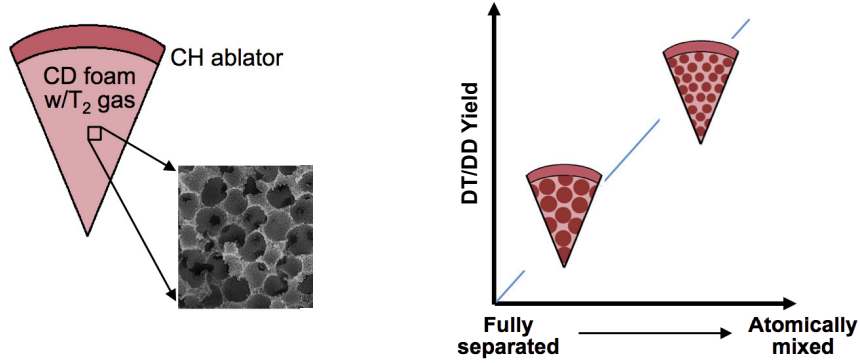


Figure 2. Pie diagram showing the capsules that will eventually be used in the MARBLE campaign. The ratio of DT to DD neutrons will increase as mix increases with smaller pore size.

to create foam with macropores of specified diameter, to encapsulate these foams into ICF targets, and to introduce tritium gas into the capsules. When in a close-pack structure, the macropores make up $\sim 74\%$ of the foam volume, and less if the ideal close-pack structure is not achieved. Techniques have been developed to machine foam spheres, characterize their macropore structure, and enclose them in capsules made from two hemispheres. Progress in the development of targets for MARBLE has been rapid and is described elsewhere [9].

Implosions of foam-filled capsules have been performed on the OMEGA laser [10] using direct drive, and on the National Ignition Facility [11] using the single-shock, exploding pusher platform [12]. These experiments were designed to test the ability of codes to correctly model the performance of foam-filled capsule implosions.

On OMEGA, capsules with 50%-deuterated foam and tritium gas fill were imploded and the DT neutron yields were measured. Due to the early state of target fabrication, many of the targets had nonuniformities in the thickness of the capsules. As a result, many of the capsules also exhibited a displacement of the imploded core from the center of the capsule in time-integrated x-ray images. When restricting the data set to those implosions with core displacements of less than $50\text{ }\mu\text{m}$ (Figure 3), the DT yield is approximately 30% of preshot calculations using the RAGE code [13]. The scaling with foam density and tritium fill pressure are seen to be in qualitative agreement with simulations.

On the National Ignition Facility, MARBLE capsules have been imploded using the indirect drive exploding pusher platform [12]. Two of the implosions were performed using the partially deuterated foam with no gas fill. Two more included a hydrogen fill gas at 1 and 3 mg/cm^3 . The DD neutron yield from these experiments (Figure 4) ranges from 50 to 85% of that predicted in simulations, depending on the hydrogen gas density and the code [13, 14] used for the simulations. Bang times were within 100 ps of these simulations.

During FY 2016, two days of experiments will be performed on the OMEGA laser using capsules with engineered foams having pore sizes ranging from 30 to 90 microns in diameter. These will be the first implosion experiments utilizing the engineered foams, and will be the first test of the MARBLE concept.

NIF experiments will continue to develop the indirect drive platform, with experimental series to measure the yield from deuterium gas in CH foam-filled capsules, a series to establish the platform using fully deuterated foam with hydrogen gas fills, and then finally the introduction of tritium/hydrogen mixtures into the gas to confirm the DT to DD yield ratio from a fine-pore foam. Engineered foams with macro-pores will be utilized on NIF starting in fiscal year 2017.

Additional supporting experiments are planned for OMEGA. These include experiments to

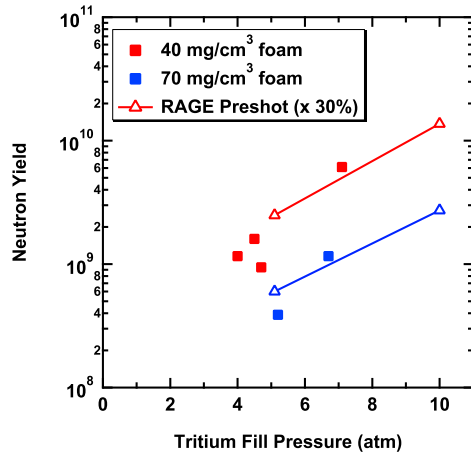


Figure 3. DT neutron yield from OMEGA NIF capsules filled with $\text{CD}_{0.5}\text{H}_{0.5}$ foam and 4 to 10 atm T_2 gas at room temperature. Yield measurement uncertainty is about 5%.

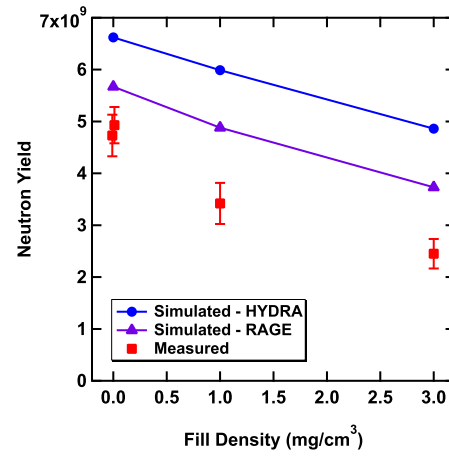


Figure 4. Simulated and measured DD neutron yield from NIF MARBLE capsules filled with $\text{CD}_{0.5}\text{H}_{0.5}$ foam and 0 to 3 mg/cm^3 H_2 gas.

visualize the interaction of a shock with a low-density void in higher density foam. These experiments will be used to validate the ability of codes to simulate the evolution of the macropores in the MARBLE experiments prior to burn time.

4. Conclusions

Development of a platform for studying the effect of heterogeneous mix on thermonuclear burn is underway. The ability to produce deuterated foam-filled capsules for OMEGA and NIF has been demonstrated. Simulations of OMEGA and NIF experiments are in good agreement with data. Initial experiments utilizing foams with macropores specified to control the heterogeneity of the mix will begin on OMEGA in 2016 and on NIF in 2017.

This work is supported by US DOE/NNSA, performed at LANL, operated by LANS LLC under contract DE-AC52-06NA25396.

References

- [1] Smalyuk V A *et al*, 2014 *Phys. Plasmas* **21** 056301
- [2] Delichatsios M A and Mathews M K 1989 *Fire Safety Science — Proc. of 2nd Intl. Symp.* p 149
- [3] Besnard D, Harlow F H, Rauenzahn R M and Zemach C 1992 “Turbulence Transport Equations for Variable-Density Turbulence and Their Relationship to Two-Field Models,” Los Alamos National Laboratory Report No. LA-UR-12303 (unpublished)
- [4] Stalsberg-Zarling K and Gore R 2011 “The BHR-2 Turbulence Model: Incompressible Isotropic Decay, Rayleigh-Taylor, Kelvin-Helmholtz, and Homogeneous Variable Density Turbulence,” Los Alamos National Laboratory Report No. LA-UR-11-04773 (unpublished)
- [5] Banerjee A, Gore R A and Andrews M J 2010 *Phys. Rev. E* **82** 046309
- [6] Fincke J R, unpublished
- [7] Mikaelian K O 1989 *Physica D* **36** 343
- [8] Smalyuk V A *et al*, 2014 *Phys. Rev. Lett.* **112**, 025002
- [9] Randolph R B *et al*, “Process Development and Micro-Machining of Marble Foam Cored Rexolite Hemi-Shell Ablator Capsules,” submitted to *Fus. Sci. Tech.*
- [10] Boehly T R *et al.*, 1997 *Opt. Comm.* **133** 493
- [11] Moses E I 2008, *Fusion Sci. Tech.* **54**, 361
- [12] Le Pape S *et al.*, 2014 *Phys. Rev. Lett.* **112** 225002
- [13] Gittings M *et al.*, 2008 *Computational Science & Discovery* **1** 015005
- [14] Marinak M M *et al*, 1996 *Phys. Plasmas* **3** 2070